Thomson Scattering in the APS linac – Yuelin Li

As part of the efforts to build a short pulse X-ray source for studying a wide variety of ultrafast dynamics in physical, chemical and biological processes, we have developed a novel scheme for generating bright, sub-100-femtosecond X-ray radiation using small-angle Thomson scattering (SATS) [1]. The scheme calls for coupling relativistic high-brightness electron bunches with high-power ultrafast laser pulses. In this scheme the laser pulse crosses the electron bunch at a small angle, the cutoff Thomson photon energy is

$$E=\gamma^2 E_L \phi^2.$$

Here γ is the electron beam energy, E_L is the laser photon energy and ϕ the crossing angle between the electron beam and the laser beam. For 0.5 GeV electron energy and 1 eV laser photon energy, to get 10 keV X-ray photon energy, the crossing angle is 0.1 rad.

Due to the small interaction angle, the laser pulse and the electron bunch almost co-propagate, hence limiting the interaction region to approximately that of the laser pulse length. With commercially available fs laser systems, it is straightforward to generate X-ray pulse with duration comparable to that of the laser. A full analysis of the scheme can be found in [1].

The scheme can be best implemented using the APS injection linac. This has several advantages over the storage ring. First a much better beam quality can be obtained using the APS photo injector, basically to the order of 5 mm mrad for the transverse emittance and 500 fs rms bunch length, and can be further improved with improvement in the performance of the drive laser and injector. The higher beam quality allows better focusing of the bunch without significantly disrupting the bunch divergence, hence better photon flux and higher brightness. Second, as a standalone system, it is independent of most of inherent operation issues associated with the storage ring. Thirdly, as the X-ray radiation is originated by the laser pulse, there is an intrinsic synchronization between the X-ray pulse and the laser pulse, ideal for pump-probe experiments.

The most important feature, of course, is the performance of the source itself, as summarized in Table 1. Also listed in Table 1 is the projected performance and costs of other ultrafast X-ray facilities for comparison. Obviously, the pulse duration of the proposed SATS is ideal for short pulse generation, generally a fact of ten shorter than other scheme, and can be very cost-effective for starting an ultrafast x-ray program at the APS. As can also be seen in the table, the SATS also deliver broadband X-ray radiation that other undulator-based sources do not provide. This can also be useful for application where broadband X-ray emission is needed.

The major technical challenge is to synchronize the laser pulse with electron bunch. We are working on pinching the jitter between the laser and the Linac rf down to 100 fs. New technique will be needed to get a better synchronization between the laser pulse and the electron bunch. It is important to note that the jitter will have not effect on the pulse duration, but only the average photon flux.

1. Y. Li et al., Phys. Rev. ST-AB 5, 04470 (2002).

Table I. Summary of the proposed APS SATS X-ray source

	APS Linac [a]	ALS Slicing	SPPS	LUX
Wavelength (Å)	1.5-0.3	6	1.5	1-10
Repetition rate (Hz)	6	10^5	30	1000
Pulse length (FWHM fs)	20	~200	200	~200
Average photon flux [b]	10^6	10^7	10^9	10^{10}
Divergence (mrad)	3	0.6		
Bandwidth	67%-200%		1%	1%
Peak brightness [c]	~10^{20}	~10^{19}	10^{25}	~10^{22}
Cost	~$1M	$9M		~$0.4B

a. Operating with a 6-Hz, 20-fs, 2-J, 800-nm laser at 650 MeV beam energy, may need a factor of 2-3 adjustment. The brightness and photon fluxes scales with the laser pulse energy and the pulse repetition rate.
b. In photons s^{-1} per 0.1% bandwidth
c. In photons s^{-1} mm^{-2} $mrad^{-2}$ per 0.1% BW